

Evaluation of Turbulence-Closure Schemes for the Coastal Ocean

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LONG-TERM GOALS

We wish to understand the dynamics of small-scale mixing processes in the ocean (e.g. turbulence, intrusions, and convection) and to determine how to parameterize their fluxes for use in larger-scale numerical models and in theory.

OBJECTIVES

We intend to test whether ocean mixing is described adequately by the turbulence-closure schemes which are being used increasingly in numerical models of the coastal ocean. Several mixing parameterizations will be examined (e.g., the K-profile parameterization [KPP] and the Mellor-Yamada parameterization [MY]). Our focus will be on shear-induced mixing, and we will make heavy use of observations of tidally-generated mixing on Georges Bank. We will employ a data-assimilative approach to examine these observations and the predictions of ocean models, in hopes of casting light on the general applicability of the mixing parameterizations. The work will also address the relevance of various aspects of the models (e.g. advection and mixing of turbulence) in the context of the physics of ocean mixing.

APPROACH

We plan to undertake a series of tests of different turbulence closure schemes using a set of oceanographic measurements of velocity and turbulent dissipation rate collected by one of us on Georges Bank during Phase I of the U.S. Northwest Atlantic/Georges Bank GLOBEC project (Burgett et al. 1996). The observations were made at two anchor stations, during two cruises. One station was in a shallow (45 m depth) well-mixed region; the other was in deeper water where stratification was just starting to develop during the first cruise and was established by the time of the second cruise. At each site, microstructure measurements of mixing were made using the tethered free-falling instrument EPSONDE (Oakey 1988), and ship-based velocity measurements were made with three RDI Acoustic Doppler current profilers.

The currents at these sites are dominated by the M_2 tide. So, as a first step in our analysis, we decomposed the velocity at each depth level into a mean component and an M_2 tidal component. The turbulent kinetic energy dissipation rate, ϵ , also had a significant component at twice the M_2 frequency (which we call the M_4 component). This higher-frequency oscillation is consistent with turbulence being generated by either the square of the tidal shear or a bottom stress that is proportional to the square of the velocity.

In the context of these observations, we will examine the terms in various turbulence-closure schemes in an effort to determine what physical processes are relevant and how they should be parameterized. In the first phase of the study, the model will be based on the 1-D turbulence closure code of Naimie (1996). Part of the work will involve adjustment of model configurations. Rather than use traditional curve-fitting calibration techniques for this task, we will use a data-assimilation technique, in which data and dynamics are blended in an optimal way. The use of data assimilation permits fine control of the interlocking of parameter values. It also affords, from the very beginning, a dynamical context. This lets us to focus on the physics, not the numerics.

WORK COMPLETED

To fill data gaps and reduce sampling bias, the velocity/turbulence observations were decomposed harmonically in time, as discussed above. The same decomposition package was added to the numerical model to facilitate comparison of the observations and the model predictions. The software was set up to permit comparisons based on velocity, on turbulence properties, or on a combination. An optimization algorithm (based on a simplex method, with multiple restarts to avoid spurious minima) was developed to allow systematic exploration of the dependence of model-observation misfit on forcing parameters (e.g., pressure gradients) and various model parameters (e.g., bottom drag coefficient).

We began with an analysis of one set of observations made at the well-mixed, shallow site. The idea was to avoid complicating effects of stratification (e.g., internal waves and baroclinic pressure gradients) at this stage. Our first step was to determine whether the model was capable of providing reasonable simulations of the observations if we used standard values of all the model parameters. This we did by running an optimization in which we adjusted only the forcing parameters, comprising mean pressure gradients in the x and y directions, together with sine and cosine harmonics at the tidal frequency (Fig. 1).

Next, noting that ocean modellers sometimes adjust the bottom-drag coefficient, C_D , in an attempt to "tune" models, we performed a suite of runs with various C_D values (Fig. 2). Two types of model run were performed. In one, the velocity data were assimilated into the model. In the second, a weighted combination of velocity and dissipation rate was assimilated.

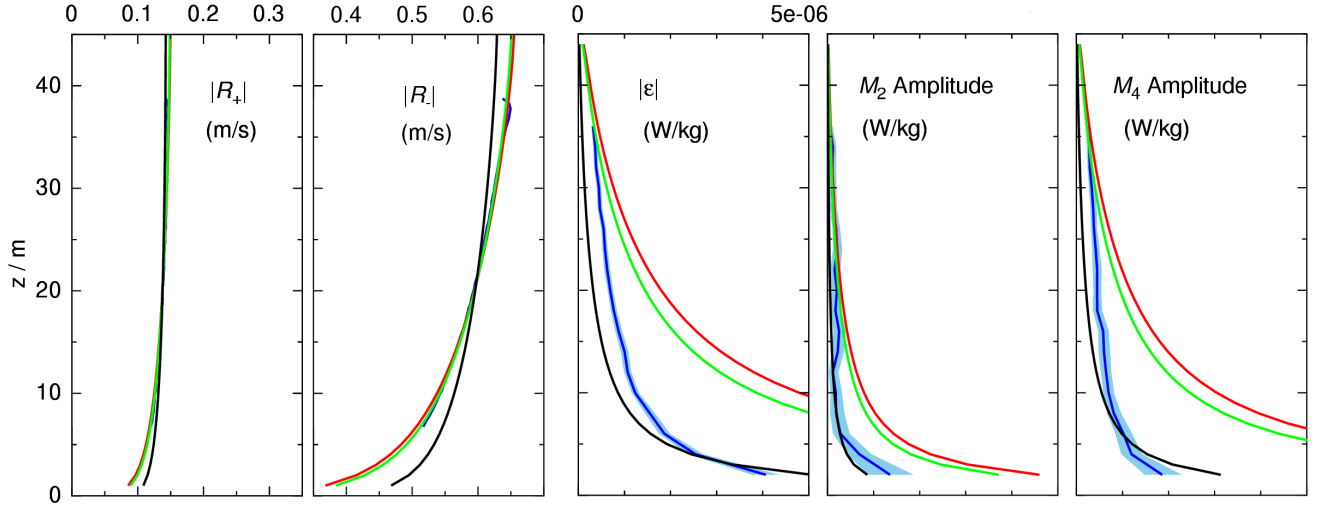


Figure 1. Observations and model predictions for the first occupation of the shallow site. The two panels on the left show the magnitude of the counter-clockwise (R_+) and clockwise (R_-) components of the M_2 tidal components. The three panels on the right show the mean, M_2 , and M_4 components of the turbulent kinetic energy dissipation rate. Each panel shows the observations as well as the predictions of several runs of the model. The solid blue lines represent observed values, with light-blue shading indicating 95% confidence limits. The other three lines represent model predictions. The red lines represent the results of the Mellor-Yamada level 2.5 mixing parameterization, with a standard bottom drag coefficient $C_D = 5 \times 10^{-3}$. The green lines represent the model results if C_D is adjusted to minimize the squared deviation between harmonic components of the observed and predicted velocity. Finally, the black lines represent the model results when the drag coefficient is adjusted to fit both the observed velocity and the observed dissipation rate.

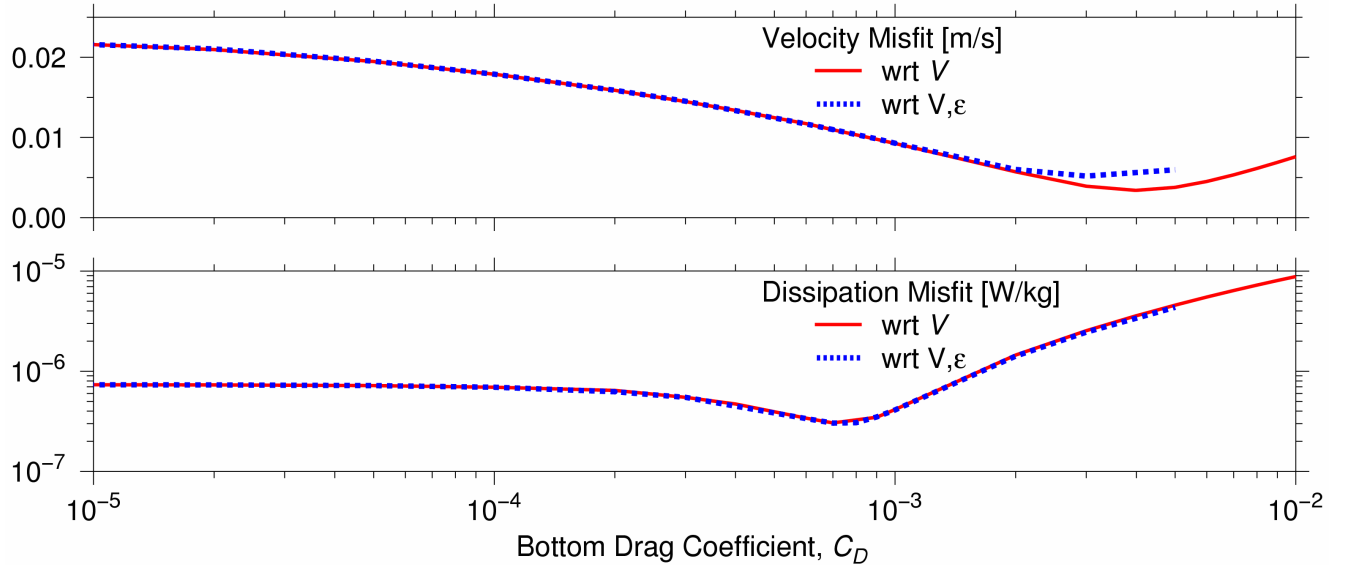


Figure 2. The rms difference between the harmonic components of the observations and model results for velocity (top panel) and turbulent kinetic energy dissipation rate (bottom panel) as a function of bottom drag coefficient. The solid red lines represent the model results when only the velocity observations are assimilated to obtain the pressure gradient terms. The dashed blue lines represent the case when both velocity and dissipation-rate observations are assimilated.

RESULTS

The standard Mellor-Yamada model uses a bottom drag coefficient of $C_D=5\times 10^{-3}$. As is evident from Fig. 2, this value appears not to be optimal for our study region. A smaller bottom drag coefficient, of value roughly 3×10^{-3} , produces an optimal misfit in velocity (although the difference is hard to detect by looking at the velocity profiles of Fig. 1). However, we noted that both cases greatly over-predict the turbulent kinetic energy dissipation rate. Much better agreement to dissipation rate is achieved if the bottom drag coefficient is reduced still further below the standard value. Indeed, optimal agreement was achieved with a value of 0.7×10^{-3} , i.e., nearly an order of magnitude less than the standard value (Fig. 2). But what if accurate predictions of both velocity and turbulence are sought? To assimilate for both velocity and dissipation rate at the same time, a weighting factor must be used to combine the observations. Using a weighting factor based on the measurement uncertainty, we found the optimal drag coefficient to be $C_D=1\times 10^{-3}$. This is basically the same as the value obtained based on consideration of turbulence alone. Each of these lowered drag coefficients yields dramatically improved predictions of dissipation rate, with only a modest increase in velocity misfit (Fig. 2).

The depth-variation of the misfit is, we argue, very informative in this context. Lower values of the drag coefficient can yield good predictions of the dissipation rate near the bottom, but this is achieved at the expense of an under-prediction higher up in the water column (Fig. 1). Thus, it seems clear that simply adjusting the bottom drag coefficient cannot make the Mellor-Yamada mixing model yield predictions of velocity and turbulence parameters that match the observations to within error bars. This model predicts a faster decay of the dissipation rate away from the bottom than is observed on Georges Bank. We think it will be fruitful to determine what physics is missing or incorrectly parameterized in the model, and this is what we will be looking at next.

IMPACT/APPLICATIONS

Results of this study will improve the accuracy of coastal-ocean models.

TRANSITIONS

At this stage, our results are not being used outside our respective research groups.

RELATED PROJECTS

N/A

REFERENCES

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